COMPOSITE FOUNDATIONS ON MALAYSIAN SOFT CLAY SOIL: APPLICATIONS OF INNOVATIVE TECHNIQUES

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others

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ABSTRACT

An innovative technique of electro osmosis coupled with vertical surcharge loading to accelerate the consolidation and stiffen Kaolin (China Clay Grade E) was investigated in this study. The geotechnical properties of this China Clay Kaolin Grade E and the design of electro osmotic consolidation chamber are discussed together with an explanation of the procedural concept of the electro osmotic consolidation chamber (i.e., the preparation of the apparatus and the clay sample, assembling of the electro osmotic consolidation chamber; and the experimental work).

The plastic limit, liquid limit and plasticity index were 35%, 53% and 18% respectively. Therefore, China Clay Kaolin Grade E is classified as MH soil, and it is predominantly a silt with high plasticity. The specific gravity of the soil is 2.65. To ensure the kaolin is saturated, all samples were prepared in a similar manner with deaired water to produce a slurry at 150% of the liquid limit (initial moisture content of 79.5%).

The electro osmotic consolidation chamber was cylindrical and consisted of the body, the base and the top cap. The body and the base of the chamber were constructed of polyvinyl chloride (PVC) tube with a wall thickness of 10.9 mm, 345 mm high and 251 mm inner diameter. The electro osmotic consolidation chamber was assembled together with a 45 mm thick flange and collar. The top cap of this chamber was based on that of a Rowe cell of similar diameter.

Twenty one tests were performed in this study with an applied voltage and one test was a control test. The test samples in the twenty one tests were all consolidated to three different phases. In Phases 1 and 2, the samples were consolidated at 15 kPa while in the Phase 3, 50 kPa was used. The electro osmotic process was only performed during Phase 2. The time of treatment, numbers of electrodes, the arrangement of electrodes, and the applied voltages were investigated in these tests.
Results from these tests indicated that the China Clay Kaolin Grade E in a 79.5% slurry form responded well to electro osmotic treatment and that electro osmotic process increased the overall stiffness of the soil as indicated by the reduced relative settlement in Phase 3 with a pressure of 50kPa.

The water content around the anodes was less than that at the cathode creating zones of higher average constrained stiffness. The tests demonstrated that the longer the time of treatment, the greater the numbers of anodes, the shorter distance between the electrodes and the higher the applied voltages associated with electro osmosis increased the average stiffness of the soil mass confirming the concept of an electro osmotic pile.

Keywords: electro osmotic merged vertical loading and electro osmotic, consolidation, electro osmotic consolidation chamber, stiffening.

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ABBREVIATIONS AND SYMBOLS

K_2O, Na_2O	alkalis (%)
Al_2O_3	aluminium (III) oxide (%)
V	applied voltage (V)
φ_{max}	applied voltage (V)
ΔE	applied voltage (V)
a	area (m^2)
A_{cell}	area of cell
$E_{stiffness}$	average constrained stiffness (kPa)
CAN	Canadian dollar
q_a	capillary of flow rate (V/m per m^2)
k_e	coefficient of electro osmotic permeability (m^2/Vs)
k_h	coefficient of hydraulic conductivity (cm/s or m/s)
m_v	coefficient of volume compressibility (m^2/MN)
H_s	comparable height of surcharge (m)
C_1	cost of electrodes per unit length ($\$L^{-1}$)
C_3	cost of electrodes of the chemical agent ($\$M^{-1}$)
C_4	cost of treatment per unit volume of the electrolyte (effluent) collected ($\$L^{-3}$)
nA	cross-sectional area of a void
I	current (A)
U	degree of consolidation (%)
R_d	delaying factor (dimensionless)
DC	direct current
δ	distance between the wall and the centre of the plabe of mobile charge
x	distance to the cathode (m)
Q	drainage rate (cm^3/s)
σ^*	effective electric conductivity of the soil medium
u*	effective ionic mobility of the ion (m^2 per sec-V)
C_2	electric energy cost ($ per kWhour)
$\in$	electrical energy requirements per gallon discharged (kWh)
$\frac{dV}{dL}$	electric field, or known as voltage gradient (V/m)

$V(x)$	electric potential at position x relative to the potential at the cathode at x = 0 (V)
k_i	electro osmotic transport efficiency (cm^3/Ampere-hours)
L	electrode spacing (m)
R_e	electrode radial spacing (m)
E	energy consumption (kWh per m^3)
u_a	excess pore pressure (kN/m^2)
F	Faraday's constant (96485 C/mol-electron)
α	factor depending upon the stoichiometry of the neutralizing reaction, dimensionless;
Fe_2O_3	ferum (III) oxide (%)
ν	flow velocity
Q_h	flow rate induced by hydraulic gradient
Q_e	flow rate induced by voltage gradient
η	fluid viscosity (Ns/m^2)
i_e, i_r	gradients
A	gross total cross-sectional area normal to the direction of flow (m^2)
A_{ineff}	ineffective area
u_o	initial excess pore pressure due to fill loading (kN/m^2)
L	length of the sample (m)
ΔL	layer thickness difference
w_L	liquid limit (%)
MHA	Malaysian Highway Authority
M_w	molecular weight of the neutralizing chemical (M/W)
H_e	negative pore water head generated by electro osmosis at x = L/2 (m)
Ψ	negative potential
N	number of capillaries (non dimensional)
F_1	number of electrodes per cell
N	number of electrodes per unit surface area ($\$L^{-2}$)
ε	permittivity of fluid (F/m)
w_p	plastic limit (%)
I_p	plasticity index (%)
PVC	polyvinyl chloride
u	pore water pressure (kN/m^2)
ζ	potential across the capillary, or known as zeta potential (V)
Ψ_o	potential at the surface

B	reactive transport rate of a species relative to the electric conductivity of a medium
v	sample volume (L)
SiO_2	silicon oxide (%)
G_s	specific gravity
c_v	Terzhagi's coefficient of consolidation (m^2/year)
T_v	time factor (non dimensional)
C_{total}	total costs per unit volume of soil to be treated ($\$L^{-3}$)
h	total hydraulic head (m)
t	total time (h)
Q	total water expelled (cm^3)
Q	total volume flow rate (m^3/s)
γ_w	unit weight of water (kN/m^3)
C_5	variable daily cost (monitoring, insurance, rentals, etc) ($\$L^{-3}T^1$)
v_h	velocity of water induced by hydraulic gradient
v_e	velocity of water induced by voltage gradient
e_o	voids ratio (nondimensional)
ΔE	voltage difference
H_2O	water
w_c	water content (%)

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Soft clays and peat soils are two kinds of soils which are known to have low strengths and low stiffnesses. The first is often a product of weathered material deposited in a marine environment; the second is derived from the decaying process of animals and plants. The mechanical characteristics of these soils are a function of their composition, history and current state. Engineering solutions have to be considered to alter these characteristics when building on or in these materials. These solutions range from permanent, hard solutions such as piled foundations, to time dependent improvement of the soil through consolidation. Piled solutions are often preferred as it reduces the risk of failure and excessive settlement but they are expensive and not sustainable given the use of primary resources. The alternative is to improve the ground using techniques such as preloading, often combined with prefabricated vertical drains and vertical sand drains; stone columns; mixing the soils with lime/cement (dry mixed method); stiffened columns; vacuum consolidation; and electro kinetics dewatering. A flow chart (Figure 1.1) developed by Bergado, et al. (1994) is a guide to the selection of the most appropriate ground improvement technique.

One method not shown on that chart yet has been in use for many years is that of electro osmotic consolidation in which water is forced out of the soil by passing an electric current through the soil between two electrodes. The technique is known to be successful at improving the mechanical characteristics but there are a number of challenges to overcome which means that the techniques has not been widely used. One of the key challenges is the breakdown of the electrodes with time stopping the process and contaminating the groundwater. Recent developments in electrodes have overcome these problems offering an alternative ground improvement technique.

An alternative approach is to use electro osmotic consolidation to create stiff soil columns within soft clay and combine that with a stiff granular layer to create a composite foundation. There is potential to use this composite foundation in soft clays in many parts of the world including Malaysia where much of the infrastructure of mainland Malaysia is built on the coastal plain.

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